D'Entrecasteaux Zone, trench and western chain of the central New Hebrides island arc: their significance and tectonic relationship

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ABSTRACT

The absence of a trench and the existence of a separate, western chain of islands in the central New Hebrides island arc are a consequence of earlier tectonic evolution, and not the result of subduction of the d'Entrecasteaux Zone as was previously suggested. Because of tectonic consolidation in the western islands prior to present subduction, a resistant block was created opposing subduction, and a trench never did form here. The d'Entrecasteaux Zone is responsible only locally for additional deformation of the subducting plate, in a way that can be regarded as an initial stage of obduction.

INTRODUCTION

In the Southwest Pacific, the New Hebrides subduction zone is marked by the downgoing Indo-Australian plate, which underthrusts the North Fiji Basin (Fig. 1). From a morphological point of view one can distinguish—as in any subduction zone—an external oceanic basin, a trench and an island arc. However, in the central part of the New Hebrides these elements are distorted or masked. Indeed, in the external oceanic basin, which is typically about 4500 m deep, a zone of high relief exists between 15° and 16° south (Fig. 2), called the d'Entrecasteaux Zone where at Sabine Bank the shallowest depth is only a few meters. The origin of this zone or ridge is discussed by Maillet and others [1]. They suggest that "... the d'Entrecasteaux Zone represents the northern arcuate extension of the north-east dipping Eocene subduction/obduction zone, located along New Caledonia/Loyalty Islands ridge, while its present morphology appeared from post-obduction extensional movements, resulting in a progressive uplift of basaltic ocean floor since Middle Miocene times".

The trench, whose maximum depth is below 9000 m at

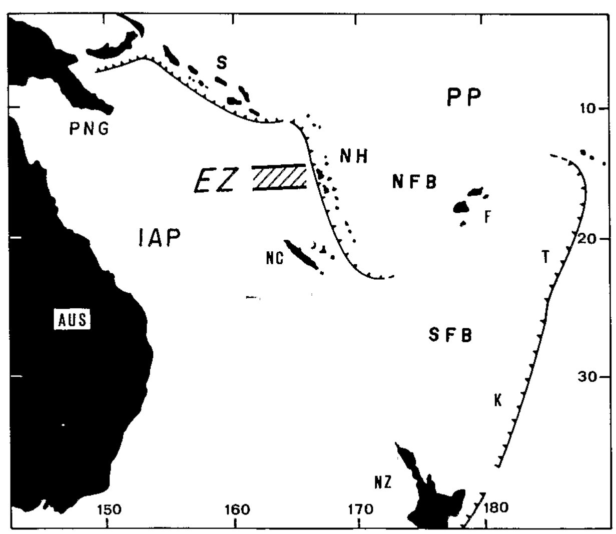

Figure 1. Location map. IAP = Indo-Australian plate; PP = Pacific plate; AUS = Australia; PNG = Papua New Guinea; S = Solomon Islands; NH = New Hebrides island arc; NC = New Caledonia; NFB = North Fiji Basin; SFB = South Fiji Basin; F = Fiji; T = Tonga; K = Kermadec; NZ = New Zealand; EZ = d'Entrecasteaux Zone.

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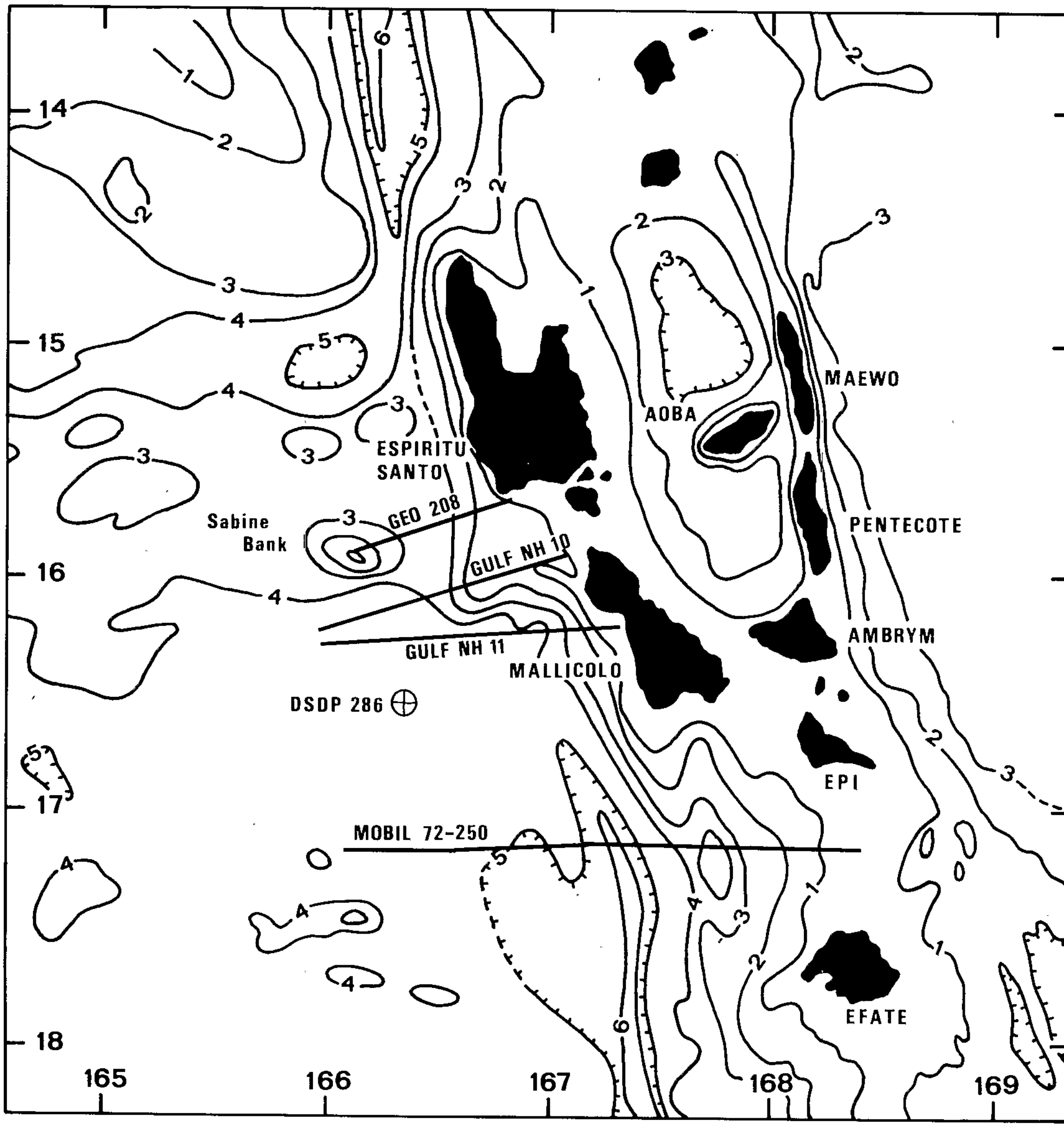

Figure 2. Bathymetry of the central New Hebrides and location of profiles. Bathymetric contours in km [25, 26, 6, and unpublished data from O.R.S.T.O.M., Nouméa].

about 12°30′S [2] disappears completely between 14°30′ and 16°30′ south, but reappears again south of this latitude.

The island arc, which includes an active volcanic chain (the "Central Chain"), presents a complex structure between 13° and 17° south. Here one recognizes a western chain formed by the Torres Islands (north of Espiritu Santo, Fig. 2), Espiritu Santo and Malekula, a well-developed central basin [3] and an eastern chain formed by the islands of Maewo and Pentecost. The two chains are underlain by Mio-Pliocene sedimentary formations of volcanic origin, but no volcanic edifices or active volcanism are found here. Furthermore, there are anomalies also in the Benioff plane underneath these islands of the central New Hebrides [4], where the maximum depth of the intermediate earthquakes is only about 250 km (Fig. 3, Section E-E′) instead of 350 km as elsewhere along the arc (Fig. 3, Sections B-B′ and H-H′).

Various authors have considered a causal relationship between these different, anomalous features [5–10]. According to a widely held opinion, the arrival at the subduction zone of the d'Entrecasteaux Zone (or Ridge) is responsible for the disappearance of the trench, and for the existence and uplift of the western island chain adjacent to the zone of collision. However, the islands of this central portion of the arc have played a special role in its earlier history, i.e. prior to the present phase of subduction which began 5 to 7 m.y. ago. Their uplifted terrains document calc-alkaline volcanism of Oligo-Miocene age in the west, and late Mio-Pliocene age in the east [11], which may be attributed to earlier phases of subduction.

Different explanations appear possible, therefore, to account for the observed situation. In the following we propose—based on the study of seismic reflection profiles—to

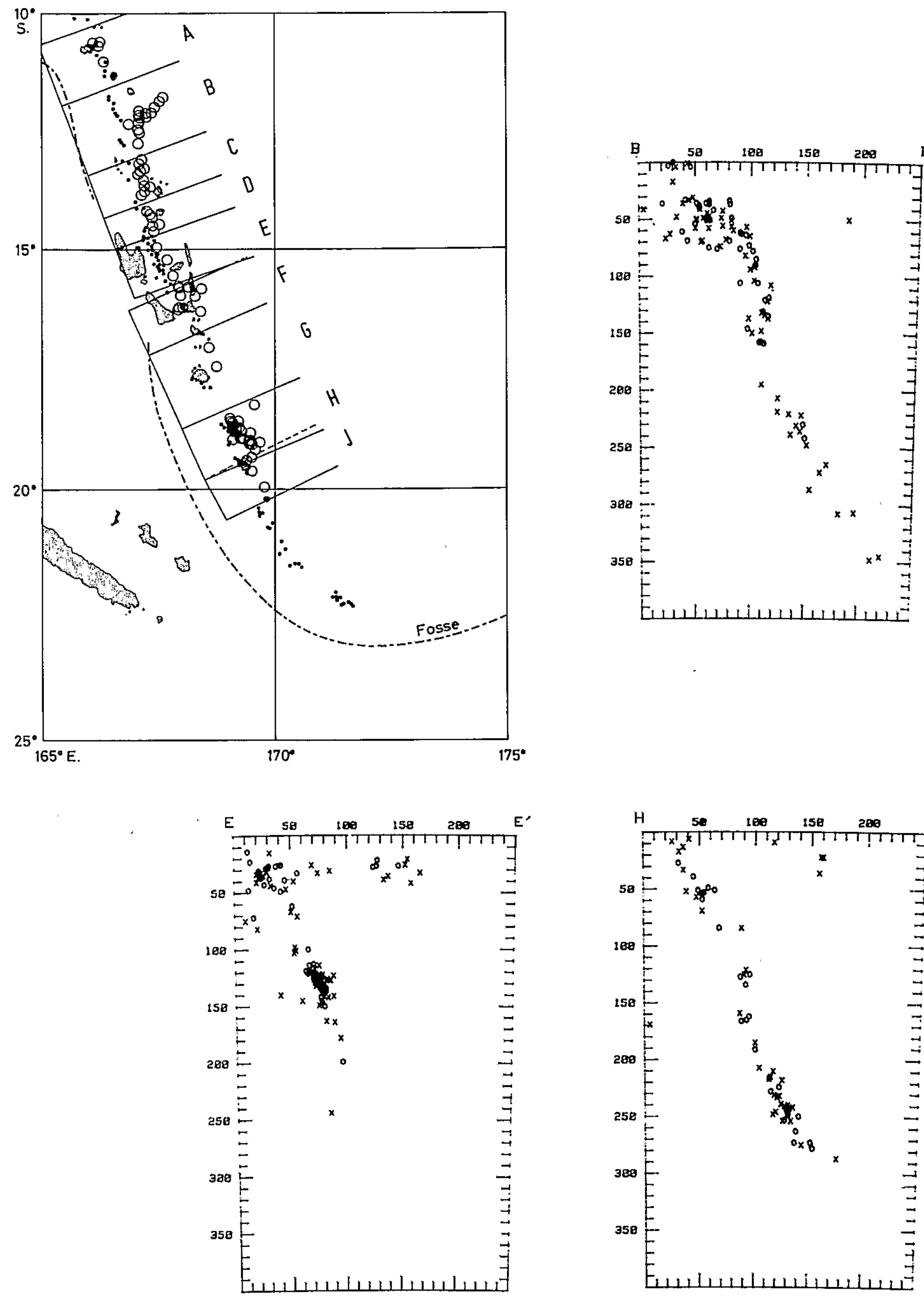

Figure 3. Seismicity of the New Hebrides [4].

examine in greater detail the relationship between d'Entrecasteaux Zone, the trench and the islands of the western chain.

BRIEF OUTLINE OF THE GEOLOGY AND TECTONIC EVOLUTION OF THE WESTERN ISLANDS

Based on the work by Mitchell [12,13], Mitchell and Warden [11], Mallick and Greenbaum [14], Robinson [15], Jouannic and others [16], and Carney and Macfarlane [17], the islands of the western chain are composed of a thick succession of mainly volcaniclastic rocks and lava flows which are the product of contemporaneous, basaltic and andesitic volcanism. Reef limestones and associated calcarenites occur locally. These, as well as large carbonized wood fragments, suggest a shallow water depositional environment adjacent to exposed land areas; turbidity currents and submarine debris flows may have transported the bulk of the sediments into deeper water.

Foraminifera suggest an early Miocene age for the 3000 to

4000 m of exposed sedimentary section which is intensely sheared, faulted and often steeply dipping and altered to zeolite metamorphic facies. Isolated red mudstone exposed in northwestern Malekula, of apparently pelagic-abyssal origin, is of unknown age but possibly pre-early Miocene. Numerous dykes and intrusions of andesite and diorite stocks preceded mid-Miocene block faulting and uplift.

Mid to late Miocene sequences, about 1500 to 3000 m thick, are less strongly deformed, less indurated and lack intrusions. They consist mainly of turbidites composed of sandstone alternating with mudstone, and of calcarenite alternating with calcilutite. The clastic material is entirely volcanic and reef detritus. Deformation, followed by profound erosion, occurred toward the end of Miocene time.

Transgressive Pliocene beds consist of non-volcanic cross-bedded sandstone, calcarenite, marl and mudstone, and are only gently deformed. Massive reef limestone of Pleistocene age is widespread, forming uplifted terraces and plateaus at elevations as much as several hundred meters above sea level.

In summary, the western islands testify to a complex tectonic-volcanic history that preceded the beginning of the present subduction phase, 5 to 7 m.y. ago. Sediments many thousands of meters thick have undergone strong deformation, uplift and erosion, and were intruded by igneous rocks. They reached a considerable degree of tectonic consolidation before the end of Miocene time, when extended land areas existed in the vicinity of the western islands. During the Pliocene, these areas were only partially submerged again under shallow seas. Such a semicratonic consolidation of the area, as postulated here, is furthermore suggested by the increased crustal thickness which in the western islands of Malekula and Espiritu Santo reaches 24 to 26 km [18].

In short, an island chain was already in existence when the present eastward-directed subduction began. This island chain, therefore, cannot have formed solely as a result of present subduction. This conclusion is important for the final considerations of our paper.

DESCRIPTION OF SEISMIC PROFILES

Figure 4 shows three seismic reflection profiles that cross the plate boundary west of the western island chain (Malekula-Espiritu Santo, 17° to 16° south; see Fig. 2); these were obtained by Mobil Oil Corporation and Gulf Oil Company on their vessels "Fred H. Moore" and "Gulfrex", respectively. A succinct discussion of these sections, from south to north, is presented below.

MOBIL 72-250. Section 72-250 (single-channel deconvolved) is slightly oblique to the direction of subduction, which is N75°E [5,10,19]. In the external oceanic basin to the west (New Hebrides Basin) the irregular basement surface is covered by a relatively thin and virtually undeformed sedimentary sequence. The trench at about 6200 m is well defined and about 1500 m deeper than the western oceanic basin. The general submarine morphology is comparable to that observed further south, i.e. west of the islands of Efate and Erromango [20,21]. However, the lower part of the trench inner slope seems to be influenced by the structure of the western island chain, which developes from here to the north.

GULF NH-11. This processed, multichannel section (2400 % CDP stack) is of particular interest, because it clearly depicts the eastward underthrust i.e. subduction of the western plate underneath the highly disturbed zone rising up towards Malekula Island in the east. However, the trench, i.e. the site of subduction, is only a slight bathymetric notch, no deeper than the average depth of the western oceanic basin (4500 m deep). In this western basin, on the other hand, important structural differences exist with regard to the Mobil section further south. Here the sedimentary sequence, which is as much as 1 sec thick and unconformably overlies basement, was determined at nearby DSDP hole 286 (Fig. 5) to be mainly Lower Tertiary deposits, but including a 64-m-thick top layer of Plio-Pleistocene volcanic ash [22]. A slight but well-marked updoming of this entire pile of sediment between 22h and 23h, where thicknesses of individual beds are neatly preserved, indicates deformation is younger than the sedimentary section, and younger of course than the irregularities of the basement at 18h-19h, or in the Mobil 72-250 section at 03h-04h immediately west of the trench.

GULF NH-10D. Seismic section NH-10D (multichannel on board stack) which is located only a short distance further north (Fig. 2), exhibits an important disturbance of great magnitude. Although in the western, oceanic basin the same sedimentary section of the subducting plate overlies an irregular basement surface, near the island arc a pronounced structural anomaly at about 10h reveals that these sediments are upthrust and faulted. On the basis of its geographic position and structural significance, this rupture or break in the subducting plate is correlated with the updoming in line Gulf NH-11 described above; it may thus represent a more advanced, i.e. more pronounced stage of the same tectonic structure as seen along that line. In other words, the updoming immediately west of the plate boundary here would have reached such proportions that rupture occurred, with the detachment and separation of an uplifted, east to northeast dipping fault block at the shallow depth of only 1000 to 1500 m. If this is so, the "trench" or plate boundary would be located along the depression at 08h-08.30h, which is clearly seen to be an important and complex fault zone toward the southern prolongation of Espiritu Santo Island.

TECTONIC INTERPRETATION AND CONCLUSIONS

As shown by the seismic profiles (Fig. 4), the morphology of the contact between the plates changes gradually from south to north. This change is characterized by the disappearance of the trench and by the deformation of the sub-

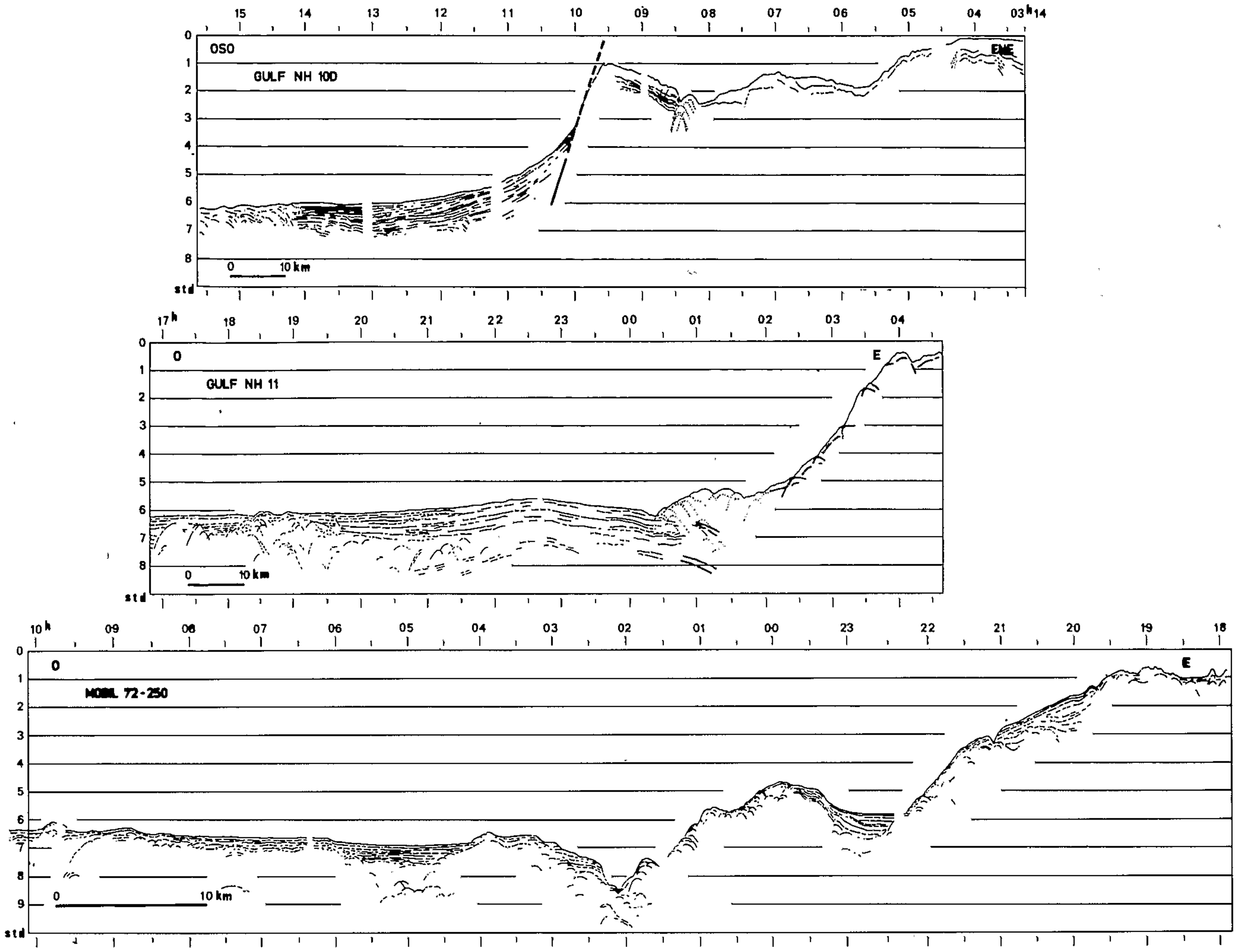

Figure 4. Seismic reflection profiles (for location see Fig. 2).

ducting plate itself. Different hypotheses can be advanced to explain this situation:

Influence of the d'Entrecasteaux Zone (or Ridge). Above all, it should be stressed that the disturbed zone, i.e. the area or sector where the geomorphic trench is missing, reaches well beyond the limits of the d'Entrecasteaux Ridge both north and south, as defined by the 4 km isobath (Fig. 2). Considering the 25° divergence between the subduction direction (N75°E) and the strike of the ridge (N100°E), one could imagine that to the south the part of the d'Entrecasteaux Ridge already subducted beneath the arc would push upwards the area of western Malekula, and thus disturb the contact between the plates, such as happens along the Tonga arc because of collision of the Louisville Ridge [23,24]. A similar line of reasoning, however, seems hardly possible for the area northwest of Espiritu Santo.

On this basis we conclude, therefore, that the d'Entrecasteaux Zone is not responsible for the disappearance of the trench.

Existence of the islands of Malekula and Espiritu Santo. As demonstrated by the geology of these islands, they existed before the beginning of the present episode of east-directed subduction, which was initiated in late Cenozoic time. On the other hand, the disappearance of the trench coincides with the position of the islands. We believe that this situation is best explained by assuming that an encounter of the subducting plate against a pre-existing, structurally resistant block that included these islands, modified the morphology of the contact. In fact, it seems logical to assume that the western part of the central New Hebrides arc, where the thick pile of mainly Lower Miocene sedimentary and volcanic rocks had been tectonically deformed and intruded by dioritic and andesitic bodies, and which had attained a greater than normal crustal thickness and was uplifted before the end of the Miocene, formed a resistant block that was opposing the subducting plate when this was approaching from the west. In other words, the central part of the New Hebrides arc had reached—before the present phase of subduction began—such an advanced stage of tectonic consolidation that it greatly complicated and disturbed the normal process

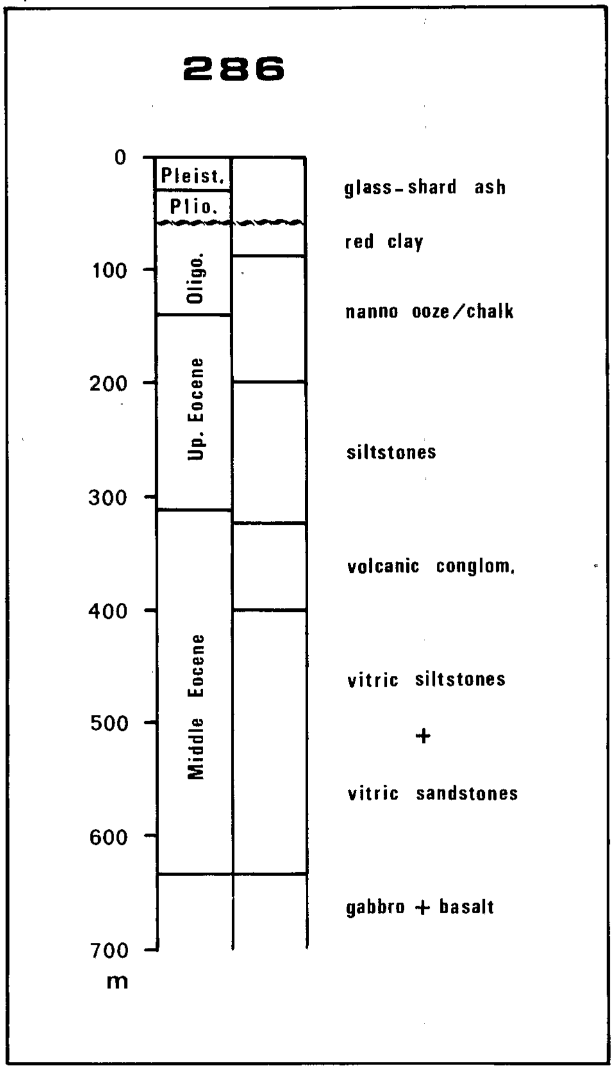

Figure 5. Simplified well log of DSDP hole 286 [22] (for location see Fig. 2).

of subduction, as compared to the areas further south. The presence of a western landmass or island chain in the central New Hebrides, therefore, is primarily responsible for the disappearance i.e. lack of the trench. In this situation, the contact of the subducting plate would be shaped to a large measure by the structural irregularities in the opposing block of the upper plate.

However, in profile Gulf NH-10D (Fig. 4) the subducting plate is conspicuously uplifted and deformed in a way that perhaps needs a special explanation. Indeed, profile Geo 208 (Fig. 6) which extends from the far southwest corner of Espiritu Santo to Sabine Bank (Fig. 2), does not show this prominent uplift. It is difficult, therefore, to attribute this localized feature to the far westward position of Espiritu Santo; although it is admitted that additional profiles, to definitely prove the point, would be necessary along the western side of Espiritu Santo.

The contact structure revealed by profile Gulf NH-10D,

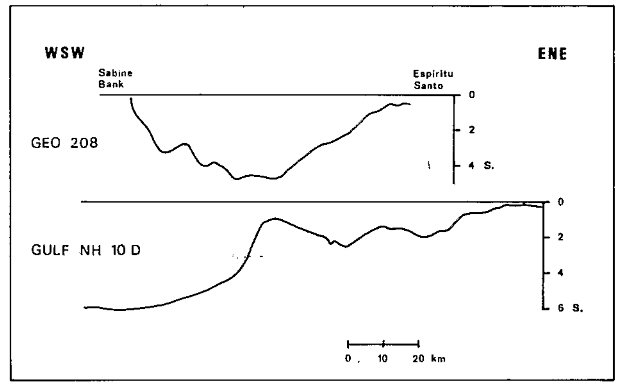

Figure 6. Bathymetric profiles Geo 208 and Gulf NH-10D.

and in this area alone, appears to show the influence of the d'Entrecasteaux Zone. Indeed, this structural complication is well aligned, in direction of strike of the d'Entrecasteaux Zone, with Sabine Bank. Also, the observed deformation of the seafloor is recent and therefore readily attributed to a subduction phenomenon. Although we are unable to define the exact mechanism of this deformation, we think that the presence of some irregularity in the subducting plate, perhaps comparable to Sabine Bank, could have provoked a blockage: not of the process of subduction itself, but of the accretion mechanism in the surficial layers of the subducting plate. Here one would have an extreme form of accretionary phenomena, with a contact structure between plates that is defined very poorly (the surface boundary of the two plates, however, being located around 08h-08.30h in profile Gulf NH-10D). The future of this type of situation is difficult to predict, but one could visualize here an initial stage of obduction.

In summary, we believe that the absence of a trench is not related to the collision of the d'Entrecasteaux Zone, but to the prior existence of a westward extension of the New Hebrides arc beneath Espiritu Santo and Malekula. In the whole, these western islands are part of a large complex that constituted an emergent landmass before the end of the Miocene, i.e. before the present phase of subduction began. Thus they have not formed as a result of subduction of the d'Entrecasteaux Zone. To the contrary, we believe that this island complex has opposed and resisted, i.e. negatively influenced the smooth process of subduction, relative to areas further south and north. As a result, no trench could ever form in this sector.

However, the arrival of the d'Entrecasteaux Ridge in the subduction zone has undoubtedly provoked additional, local deformations of the subducting plate.

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